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Procedia
Social and Behavioral Sciences

Procedia - Social and Behavioral Sciences 54 (2012) 27 – 36

EWGT 2012

15th meeting of the EURO Working Group on Transportation

A study on factors affecting the effective eco-driving

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Abstract

In order to reduce CO_2 emission of automobiles, promotion of eco-driving is considered being effective. As a tool of promoting the eco-driving, some driver assistance systems have been developed for improving the drivers' techniques by providing information after having evaluated the drivers' behaviour when driving. What can make the drivers improve their driving to be more economically and ecologically attracts us to conduct this study. In this paper, factors affecting drivers' improvement of eco-driving are reported on the basis of our analysis of the data collected from a social experiment undertaken during October 2009 and January 2010 in Toyota City.

Keywords: Eco-driving; driver assistance system, provision of information, travel behavior, probe car / floating car, sociale experiment

1. Introduction

In Japan, the CO2 emissions from automobiles shared 87.3% (Foundation for Promoting Personal Mobility and Ecological Transportation) of that in the transportation section in 2007 fiscal year (from April 2007 to March 2008). On the other hand, the period from 2008 through 2012 is the first promise period of the Kyoto Protocol. We cannot wait for a long time to promote the countermeasures for the global warming issue, so it is very important task to reduce the CO2 emissions from automobiles. As expected to be an effective approach, eco-driving has been listed in the measure menu by the central government and many local governments in Japan. And as a result, the active promotion activities have been undertaken up to now.

To promote the eco-driving is a very hard work. Up to now, the most widely used approaches may be just calling the people's attention for the climate change problem/the global environment issue or providing the

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information on the reduced amount of the fuel consumed when making eco-driving. For example, Ichihara et al. developed a driver assistance system with which the practice of eco-driving had been evaluated and then the evaluation result was provided to the drivers in order to improve the eco-driving techniques of the drivers. As an OBU (on board unit) system, Techtom developed a so-called Nennpi-Manager to evaluate the practice of eco-driving real time. In addition, NEC developed a system, named DriveManager, collecting the data from more than one vehicle and providing the information such as ranking results by the fuel consumption after having aggregated by the computer. The authors have also developed a data collection and information provision system (Ando et al, 2010) and then make a discussion on the effects of the eco-driving (Ando et al, 2011). Furthermore, the authors have implemented a test run to evaluate the eco-driving (Ando & Nishihori). In Europe, Beusen et al. reported the fuel consumption was a reduction of 5.8% although there were large differences between individuals. What kinds of driving are eco-driving? To answer this question, Ericsson (2001) gave a detail analysis on which pattern factors were main factors influencing on fuel-use and exhaust emission on the basis of a classification on the driving patterns (Ericsson, 2000). As a result, 62 driving patterns parameters were calculated for each of 19,230 driving patterns collected in real traffic and finally were reduced to 16 independent driving patterns factors by using factorial analysis. Further, CIECA implemented an internal project and summarized the experiences in “expert” countries: Finland, Netherlands, Germany, Switzerland and Sweden. All of these studies allow us understanding the effects of the eco-driving quite clearly. Moreover, Zarkadoula et al. reported the effect for the bus drivers. In this paper, we will report mainly about the analysis output on the relations among the information we provided, the drivers’ characteristics, the change of the drivers’ behaviour and the effects on the reduction of the CO2 emissions when driving a car.

2. Outline of eco-driving promotion system

Communication network of the system is depicted in Fig. 1. The driving data were collected by the BCALs (Behavioural Context Addressable Loggers in the Shell) put on the dashboard of the cars. Reasons for that we adopted the BCALs are its relatively low cost and its relatively high performance. The data include the longitude, the latitude, the time, the acceleration in the three directions etc. of the car.

The sizes of the BCALs are 98 mm long, 61 mm wide and 18 mm high. Its weight is only 100 g. The operation needed is just only to switch power on or off. Therefore, the people can easily put it into their pockets like a mobile phone or put it on the dashboard of their cars. The power may be from the cigar-socket in the car or just from the rechargeable battery with the capacity of 750 mAh inside. As it can catch the GPS (Global Positioning System) signal, we can obtain the position and time information so that we can compute the travel speed, too. The sensor of the accelerations in three directions equipped in the BCALs let us be able of knowing the accelerations of the car in three directions. The accelerations in three directions may be used to understand the driving is smooth and safe or not. Furthermore, the communication module of a Japanese mobile phone carrier has been installed inside, too. This communication module makes us be able to get the real time data about the driving when the BCALs unit is equipped. In addition, the function of A-GPS (assisted GPS) can be applied for positioning even under the ground such as the subway station et al. The measuring time intervals can be set between 1 to 1800 seconds (2 seconds was used in this study). The communication time intervals can be set between 60 to 1800 seconds or before sleeping. The sleeping mode may be set to automatically occur after the certain time period since the engine-off of the car (1800 seconds after the engine-off was adopted in this study). Moreover, all parameters given here may be changed on-line and remotely.

The collected data are sent to server PC by the packet transmission through the mobile phone communication module. The received data in the server PC are processed automatically by program which has been prepared by managers in advance and then some of them are sent to the mobile phones of users and upload to website. Therefore, the users may access the website and check all respective with the defined indicators, too.

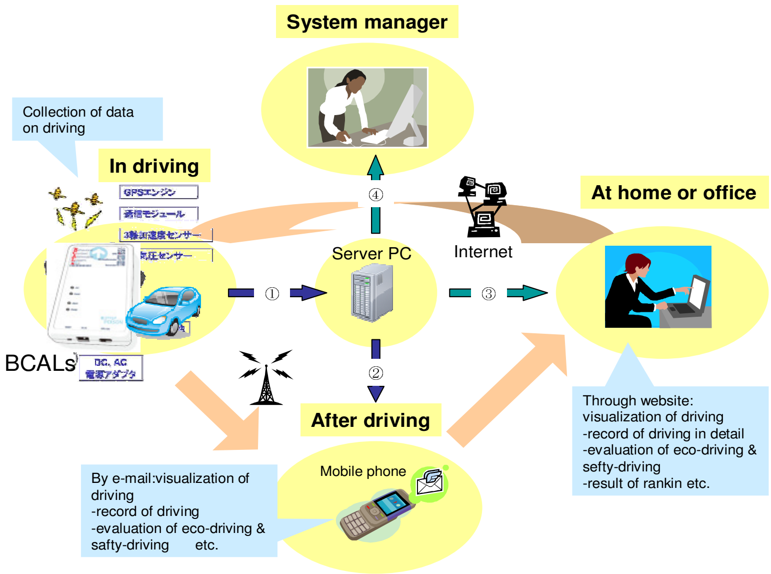


Fig. 1 depiction of the communication network of the system

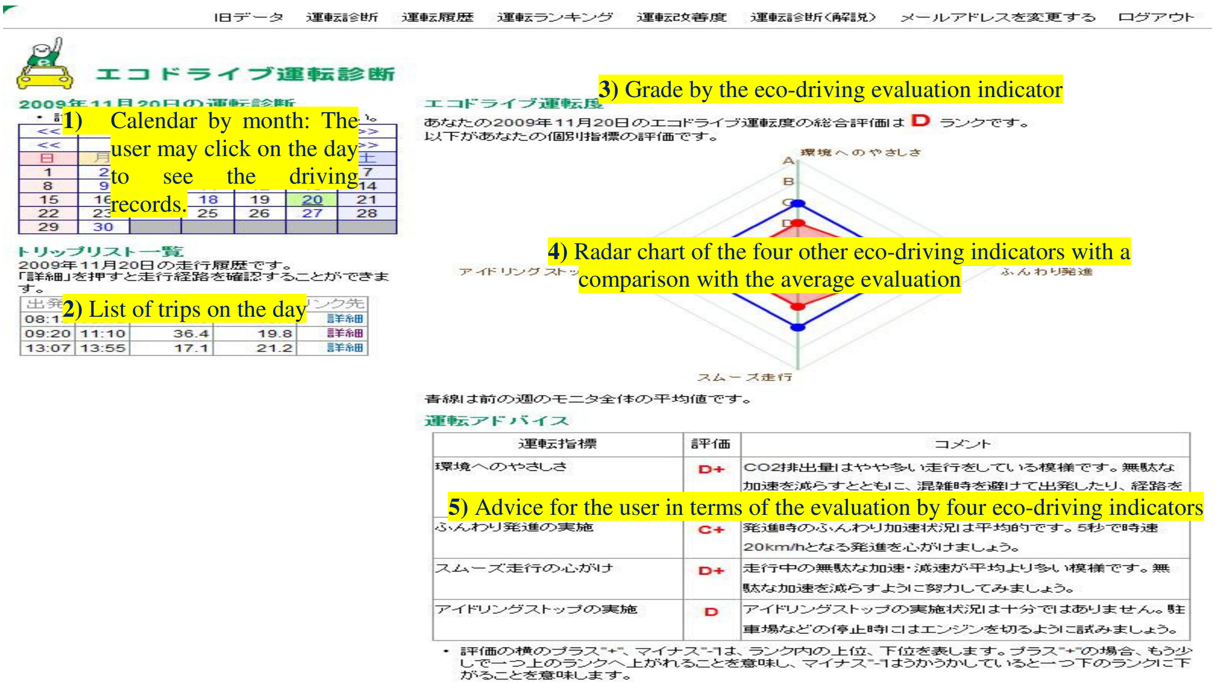


Fig. 2 Main page of eco-driving evaluation

The information provided through website is depicted in Fig. 2. Part 1 shows a calendar by month. The user may click on the day to see the driving records of that day. Part 2 gives the list of the trips on the day specified by a click in Part 1. Part 3 is the grade by the eco-driving evaluation indicator. Part 4 is the radar-chart of the four eco-driving indicators with a comparison with the average evaluation. Part 5 is the advice for the user in terms of the evaluation by the four eco-driving indicators. The contents including other items, such as the trends of the evaluations by the indicator and by day for a specified month, are summarized and described in Table 1.

Considering the communication speed etc. of mobile phone and the data transmission cost, contents of the e-mail are limited. The contents are summarized in Table 2. Here, all are about the trip.

Table 1 Summary of contents of information provision through website

Type	Contents of Information
Evaluation indicator of eco-driving (3) in Fig. 2)	The indicator defined as the summation of points respective with each indicator given above
Radar chart of evaluation results (4) in Fig. 2)	The radar chart of the four eco-driving indicators, those are Starting indicator, Travel indicator, Idling indicator, Emission indicator, with a comparison with the average evaluation
Advice for eco-driving (5) in Fig. 2)	The advice for the user in terms of the evaluation by four eco-driving indicators
Change of evaluation during the specified month	Trends of the evaluations by the indicator and by day for a specified month
Change of ranking results	The user's position when ranking up over all users
Comparison results and comments	The comparison of all eco-driving indicators between the normal driving and the eco-driving by the evaluations
Travel route of a specified trip	The driving route drawn on the basis of GPS data
Evaluation results of three safe-driving indicators	The numbers of the steep acceleration, the steep deceleration and the steep handling

Table 2 Summary of contents of information provision by e-mail

-Starting time of the trip
-Ending time of the trip
-Grade evaluated by the emission indicator
-Travel distance(km)
-Average travel speed(km/h)
-Number of steep acceleration, deceleration, and handling

3. Eco-driving promotion social experiment

That the information provision can change the people's behaviour has been proved in many studies in the field of the Mobility Management (Japan Society of Civil Engineers). Regarding the promotion of eco-driving, Nishikawa et al. showed that only the training of eco-driving techniques cannot approach the effects for a long term. However, the fuel consumption information may make the drivers keep to do eco-driving.

On the basis of the experiences of the authors in the traffic safety education and the travel demand management, we thought that there are the appropriate approaches with the information provision. The best approach is not equal to the approach having the highest frequency. Thus the following assumptions are made.

- *Assumption 1: Providing the information with high frequency (e.g., everyday)*

  Very frequently! It is very friendly. However, the effects of behaviour change may not be felt because of a too short term. As a result, the information users may get into a groove and not be affected by the information provision further.

- *Assumption 2: Providing the information with middle frequency (e.g., several time a week)*

  When the information users read the information, they may have the memory of the passed accesses so that they may compare them with the latest ones. These kinds of comparison can make the users keep in the eco-driving status for a long term.

- *Assumption 3: Providing the information with low frequency (e.g., once or less a month)*
  The effect of information provision cannot be expected. However, the drivers, who want to improve their driving techniques despite of the information provision, should be considered separately.

Surely, other than the information provision, the characteristics of the drivers such as the ages, the driving characteristics such as the travel distance and the driving styles have the influence on the changes of the driving techniques.

In order to make the analysis on these factors, we conducted a social experiment. The social experiment was conducted in Toyota City during October 1, 2009 to January 31, 2010. According to the terms when the monitors had taken part in the social experiments, they may be divided into three groups. The terms for each group were 7 weeks, 2 months and 4 months respectively. All monitors had been requested to behave as usual during the first week. Since the second week, they had been requested to behave by referring the information provided if they like. Regarding the total number of the monitors, 146 vehicles have been finally participated our project. Here that we don't use the word "person" but the word "vehicle" is because some vehicles are the companies owned ones so that many different persons may drive the same cars. As a result, we collected the data of 7,900 vehicle-days totally over 519,000 kilometres and 21,000 hours. The monitors can be divided into two different groups: one is the normal monitors with the 50 persons and the other one is the unspecified monitors who made use of the companies owned cars, 96 vehicles in total. For the former group, all information provision has been carried out. However, regarding the latter group, the information provision was sent to a specified person or the clerk being charge in the management of the companies owned cars as the drivers would be different each day. Considering the behaviour of the monitors made use of the companies owned cars is quite different with that of the normal monitors, we report the results of the social experiment in terms of the analysis for the normal monitors in this paper.

Regarding the indicators having been used as the information to be provided, we defined them by considering the general recognition in Japan recommended by the Association for Promotion of Eco-Drive as the followings.

- *Starting indicator = (number of starts have been accelerated faster than 20 km/h in five seconds) / (total number of starts)*
- *Travel indicator = (accumulated time to change speed faster than 20 km/h in five seconds) / (total travel time)*
- *Idling indicator = (accumulated time of engine on when stopping) / (total stopping time)*

Furthermore, to evaluate the CO_2 emission for each trip, the following indicator is proposed. Here, the estimated CO_2 emission amount is calculated by the Equation (1) proposed for the gasoline-powered passenger car, being same as what we made use of, by Oguchi et al. And the standard CO_2 emission amount is obtained as the computed amount when the car runs by following JC08 mode. The JC08 mode is a test run mode of fuel consuming defined by Japanese Government in 2006.

- *Emission indicator = (estimated CO_2 emission amount per kilometre) / (standard CO_2 emission amount per kilometre)*

$$E=K_C(0.3T+0.028D+0.056\Sigma\delta_k(V_k^2-V_{k-1}^2)) \quad (1)$$

Where E = CO_2 emission amount (kg- CO_2)

T = Travel time (sec)

D = Travel distance (m)

k = Number of points where the speeds are observed

δ_k= 1 (when speed is greater than that at the previous point) or 0 (others)

V_k = Travel speed at point k (m/sec)

K_C = Coefficient of CO_2 emission (0.002322kg- CO_2/gasoline (cc))

Finally, evaluation indicator of eco-driving is defined as the summation of points respective with each indicator given above. The points of 5 to 1 are given in terms of the grades evaluated by each indicator. Then the eco-driving evaluation indicator can be ranked by five grades in terms of the total points. Here, in order to evaluate safe-driving, three indicators have been proposed on the basis of the data collected by the BCALs.

- *Steep acceleration = when an acceleration being bigger than 0.2G ($G=9.81m/s^2$) is detected in the direction of moving forward, the place and the action is recorded.*
- *Steep deceleration = when a deceleration being smaller than -0.2G is detected in the direction of moving forward, the place and the action is recorded.*
- *Steep handling = when the absolute value of an acceleration or deceleration being bigger than 0.2G is detected in the left or right direction when moving forward, the place and the action is recorded.*

4. Analysis on relations between change of eco-driving effects and influence factors

By using the emission indicator given in the above, we made an analysis on the relations between it and the factors that had been listed in Table 3. Then the results are shown in Table 4. Judged by the statistical significance, the explanatory variables No. 10 and 12 are significant at the 1% level, and the variable No. 4 is significant at the 5% level. Especially, the correlation coefficient of No. 12: Rank of average travel speed is -0.826. This shows us a very direct result that the faster average speed evaluation, the better the emission indicator is. As for the variable No. 10, the longer average running distance per day can make the emission indicator better. Regarding the last significant variable No. 4, the emission indicator may be decreased by the motivation of the monitor if he/she is interested in the social experiment.

5. Influence of information frequencies

In order to make the analysis on the influence of information frequencies, we make use of the Quantification Method I (Hayashi). Considering the significant factors have been made clearly in the above Section, the two variables of No. 4: Motivation of participate in Social Experiment 3 (interested in social experiment) and No. 10: Rank of average of running distance is included in the analysis, too. That the variable No. 12 is not included here is because the speed factor has been included by Equation (1) and its effect has been reflected in the emission indicator, too. To discuss the effects by the durations, we defined the social experiment by three durations as the followings. Then, the analysis for three groups classified by the information frequencies can be carried out with

Table 3 Summary of variables

No.1 Age: Age of driver
No.2 Motivation of participate in Social Experiment (1): Dummy variable. Being 1 when the monitor’s motivation of participate in social experiment is “improve eco-driving techniques”
No.3 Motivation of participate in Social Experiment (2): Dummy variable. Being 1 when the monitor’s motivation of participate in social experiment is “interested in eco-driving”
No.4 Motivation of participate in Social Experiment (3): Dummy variable. Being 1 when the monitor’s motivation of participate in social experiment is “interested in social experiment“
No.5 Motivation of participate in Social Experiment (4): Dummy variable. Being 1 when the monitor’s motivation of participate in social experiment is “act against global warming”
No.6 Motivation of participate in Social Experiment (5): Dummy variable. Being 1 when the monitor’s motivation of participate in social experiment is “get TOYOTA ECO POINT”
No.7 Motivation of participate in Social Experiment (6): Dummy variable. Being 1 when the monitor’s motivation of participate in social experiment is “save gasoline”
No.8 Recognition of Eco-driving, Practice of Eco-driving: Dummy variable. Being 1 when the monitor had known the way of eco-driving

and had done eco-driving; Being 2 when the monitor had known the way of eco-driving but had not done eco-driving; Being 3 when the monitor had not known the way of eco-driving and had not done eco-driving
No.9 Idling Stop Function: Dummy variable. Being 1 when the monitor's car have the function of idling-stop
No.10 Rank of average of running distance: Rank of average running distance by day in a term of social experiment: under 30km/day: 1, under 50km/day: 2, over 50km/day: 3
No.11 Rank of frequency of driving: Rank of ratio of driving day to the all-day of social experiment: under 70%: 1, under 90%: 2, over 90%: 3
No.12 Rank of average travel speed: Rank of average speed in a term of social experiment: under 25km/h: 1, under 30km/h: 2, over 30km/h: 3

Table 4 Analysis results of correlation analysis CO_2-variables

No.	Correlation coefficient	Judgment
1	0.0377	
2	0.1481	
3	0.1655	
4	0.3251	*
5	-0.1210	
6	0.0509	
7	0.2100	
8	0.0070	
9	-0.0872	
10	-0.5800	**
11	0.1452	
12	-0.8260	**
No of Samples		48

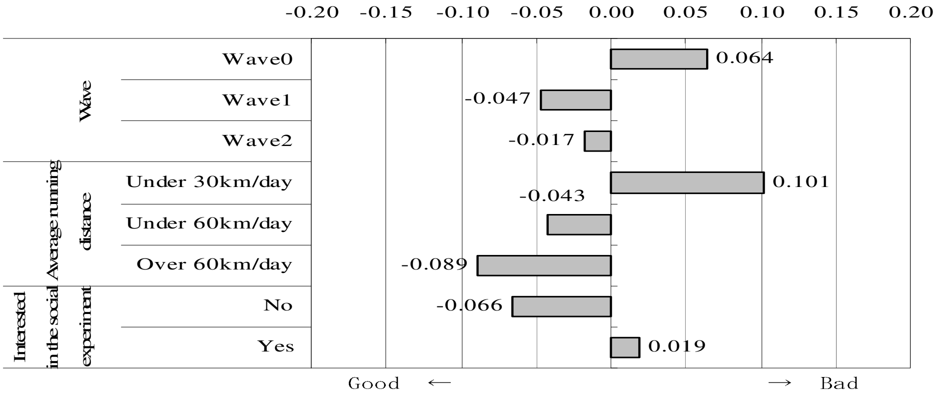
**:1% significant, *:5% significant

respective to the three assumptions we made. As the results, the all category scores obtained in terms of the Quantification Method I are given by Fig. 3 to Fig. 5 respectively.

- *Wave 0= the first week (driving as usual);*
- *Wave 1= the second week (doing eco-drive);*
- *Wave 2=the third week and after (doing eco-drive continually).*

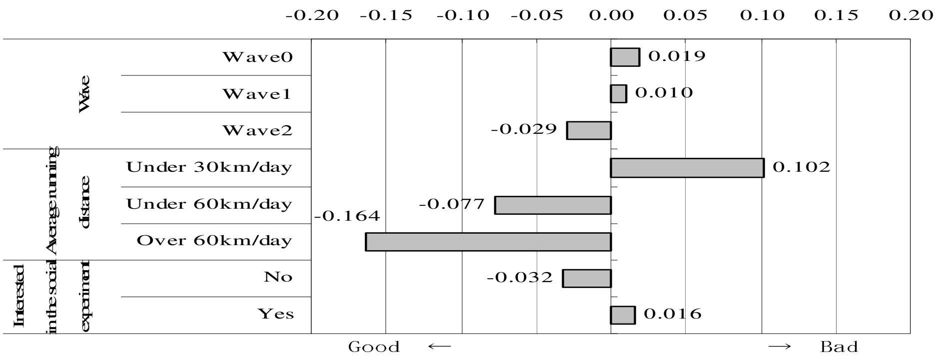
When we observe the results, we can know that the ranges (the differences of the largest score and the smallest score) of "average running distance" are the largest among the three variables despite of the frequencies of checking information. The scores respective with the category "under 30 km/day" of the variable "average running distance" are positive for all three cases divided by the frequency checking the information. On the other hand, the scores respective with the other two categories are negative. It implies that it is relatively more difficult for the drivers with the short trips to improve the value of CO_2 emission indicator.

Let see about the item "wave". Focusing to the "checking the information almost every day" group, the score respective to the wave 2 is worse than that of the wave 1. This is just what we can get from the assumption 1. Regarding the "checking information several times in a week or a month" group, the score respective to the wave 2 is better than that of the wave 1. This can be explained easily by the assumption 2. On the other hand, as for the "checking information only a few times" group, the score respective to the wave 2 is also better than that of the wave 1 although the difference is smaller than that of the "checking information several times in a week or a month" group. This result cannot be easily explained by the assumption 3. The other factors should be analysed further.



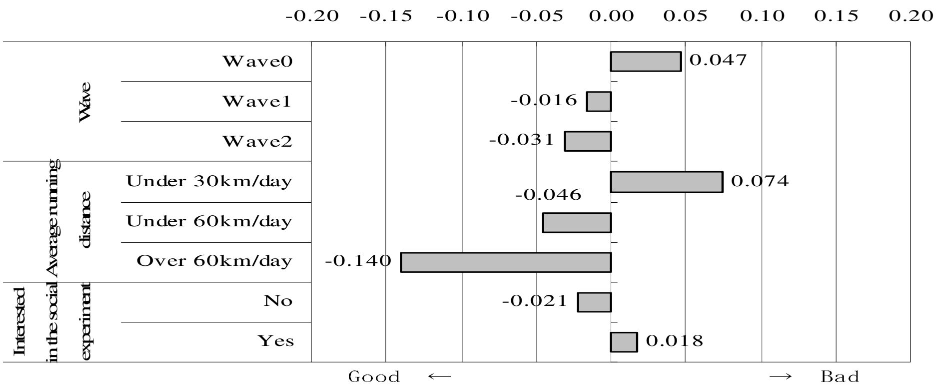
No. of samples: 9, Multiple correlation coefficient: 0.647, Constant: 0.968

Fig. 3 Analysis results using *Quantification Method I* (Checking information almost every day)



No. of samples: 21, Multiple correlation coefficient: 0.711, Constant: 1.007

Fig. 4 Analysis results using *Quantification Method I* (Checking information several times in a week or a month)



No. of samples: 11, Multiple correlation coefficient: 0.753, Constant: 0.966

Fig. 5 Analysis results using *Quantification Method I* (Checking information only a few times)

Regarding the item "interested in the social experiment", all three figures show that the category "yes" makes the CO_2 emission indicator be larger. That is a same tendency what we have known from the analysis results of correlation analysis in Table 4. It can be explained by that the monitors who were "interested in the social experiment" were not interested in improving their eco-driving techniques.

These results tell us that the information provision should be made according to the individual's characteristics. For example, for the drivers who were only interested in the social experiments, the information calling them to promote the eco-driving should be closed up. For the drivers who do not check the information provided, the motivation to check the information should be studied and reflected in the system. For the drivers who have the same or similar characteristics such as in the average driving distance et al, the ranking in a small group may be provided to call their competitive spirit of improving the eco-driving.

6. Conclusions

In terms of the analysis on the factors affecting the effective eco-driving, the following conclusions can be achieved.

- *Judging by the CO_2 emission, the information provision frequency in the viewpoint of providers or the information checking frequency in the viewpoint of the users, the average speed, the average driving distance and the individual's characteristics are the significant factors.*
- *Regarding the information provision / checking frequency, the two assumptions have been proved. When providing the information with high frequency, the information users may get into a groove and not be affected by the information provision after a certain time term as that at the beginning. Furthermore, when providing the information with middle frequency, the information users may keep in the eco-driving status for a long term.*
- *Because of the effects are related with the individual's characteristics, the on-demand system providing the information according to the personal characteristics is expected to realize the best improvement for the effective eco-driving.*

Acknowledgement

This study was a part of the Green Mobility Model Project for Constructing a Low-Carbon Transport System financially supported by Japanese Ministry of Economy, Trade and Industry and implemented by Council for Green Mobility. When this study was undertaken, we were supported by Prof. Takayuki Morikawa of Nagoya Univ., all members of the council and many other people. Furthermore, this presentation and publication was supported by Grants-in-Aid for Scientific Research (Kakenhi) of Japan. We wish to express our gratitude here.

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